Magneto-optical Measurements using a Hybrid Magnet(Part II. Several Instruments and Techniques Developed in HFLSM)

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Magneto-optical Measurements using a Hybrid Magnet*

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Abstract

Magneto-absorption spectra were obtained in the fields up to 23 T by means of a hybrid magnet at Tohoku University. The absorption was obtained by measuring the intensity of transmitted light through the sample. Optical fiber systems were utilized for the light transmission, which enabled rapid assembly of the light pass within a restricted machine time. The spectra were taken in the wavelength region of about 300 to 2000 nm. The monochromator was fully remote controlled from outside of the magnet room by a computer.

I. Introduction

Magnetic field effects for the absorption spectra have been investigated in various materials since the initial study was made by Faraday at the end of 19-th century. At first, electromagnets were used for the field generation which could produce flux density up to 4 T[1]. In the visible range, photographic techniques have been a very powerful tool to observe spectra in a short interval. Pioneer scientists used a xenon flash combined with a pulsed magnet for measuring magneto-absorption spectra in high field region[2]. Recently, an opto-microchannel analyzer was developed, which began to be used instead of the photography[3,4]. However, the duration time of the pulsed magnet is limited to be several millisecond at most, so that it is difficult to get the high resolved spectra, especially in the near infrared region. Steady magnetic field is essential to observe detailed magnetooptical effects.

The magnetic fields up to 18 T can be generated by a superconducting magnet alone. At present, much higher field is left

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to a resistive magnet with a large consumption of electric power. A hybrid magnet was proposed to generate the highest steady field practically by inserting the resistive magnet in a superconducting magnet. Construction of the hybrid magnets in Japan was made at High Field Laboratory for Superconducting Materials in Tohoku University[5)]. Three magnets have been built up until now. By using one of them, the world highest record of 31.1 T was generated in 1986. Previous to the success, we have planned to make a system to measure the magneto-absorption spectra using these hybrid magnets.

Since the hybrid magnet contains large superconducting mag-net, a monochromator and a detector must be placed several meters far from the magnet to avoid the large leakage flux. An optical fiber system was employed for the distant light transmission. This system realized Voigt configuration besides Faraday one using a londituginal field. Moreover, an immediate setting of light pass was achieved within a restricted machine time of hybrid magnet. The wavelength scanner and optical filters of the monochromator were remotely controlled, as all the person are kept out during the excitation of the magnets.

II. Experimental Arrangement

The light system of the magneto-absorption spectrometer using a hybrid magnet is shown in Fig. 1. The monochromatic light is led to a dewar through a flexible optical bundle fiber. Single fibers with large core are used inside of the dewar for reducing ineffective area against the light transmission, because flexibility was no longer neccesary inside of the cryostat. The transmitted light through the sample is sent to a detector by another bundle optical fiber system. The sample can be cooled down to 1.3 K by evaporating liquid helium. Field strength was changed by adjusting the currents for the outer superconducting magnet and inner resistive one.

Light source and monochromator. A tungsten halogen lamp (24 V, 250 W) or a xenon lamp were used for the light source. An image of the lamp is focused on the entrance slit of the monochoromator using a toroidal mirror. The dispersion of the monochoromator (JBL: CT-50 C) is 1.5 nm/mm for a grating of 1200 grooves. The size of the grating and focal length are 84 × 84 mm^2 and 50 cm, respectively, resulting in f number of 5.3. The grating can be easily replaced to that of 300 graves in order to extend the wavelength region. An optical filter box is attached to the entrance side of the monochromator, in order to cut off the higher harmonics of the grating. Selection of the filter and the scanning of the wavelength can be controlled by a computer using a GP-IB network.

Optical fibers. Exit light from the monochromator is introduced into a flexible optical bundle fiber in a specially made mirror box. The flexible bundle fibers of about one millimeter in thickness are made up of a hundred thin optical fibers (80 μm in core diameter and 125 μm in clad diameter). The end of the bundle fiber, which is connected to the mirror box, is aligned in a straight form in order to make good use of the monochromatic light which passes through the

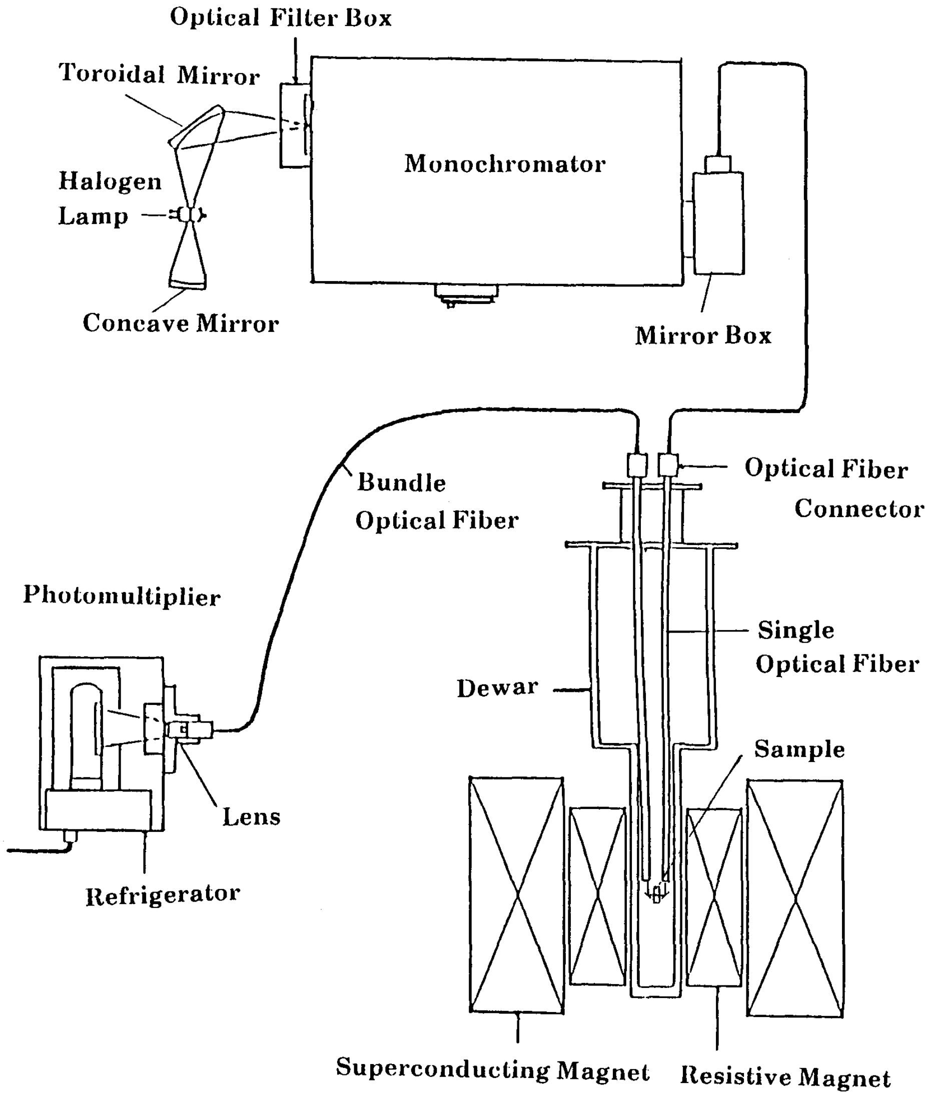

Fig. 1. Block diagram of the magneto-absorption spectrometer.

exit slit. The bundle fibers were made by Furukawa Electric Wire Co. Ltd. The single fibers with large core of 1 mm were made by Mitsubishi Electric Wire Co. Ltd.

Sample holder. Figure 2 shows the vicinity of the sample in detail. Emitted light from the end of the optical fiber is focused down to the sample by a convex lens. The light is hit by two plane mirrors and is sent to another optical fiber through the respective lens. The diameter and the focal length of the lenses are both 10 mm. Smaller lens is not suitable in this system. Since the thermal expansion is different between the quartz fiber and the stainless steel pipe, the end position of the fiber moves 2 mm by the temperature change. Slight displacement of the fiber brings about the large deviation of focal position with short focal length lens.

The Voigt and Faraday configurations are realized as follows. As the magnetic field is applied in parallel to the optical fibers, the Voigt configuration is achieved by setting the sample between the plane mirrors. In the Faraday configuration, the sample is inserted between the lens and the end of the fiber.

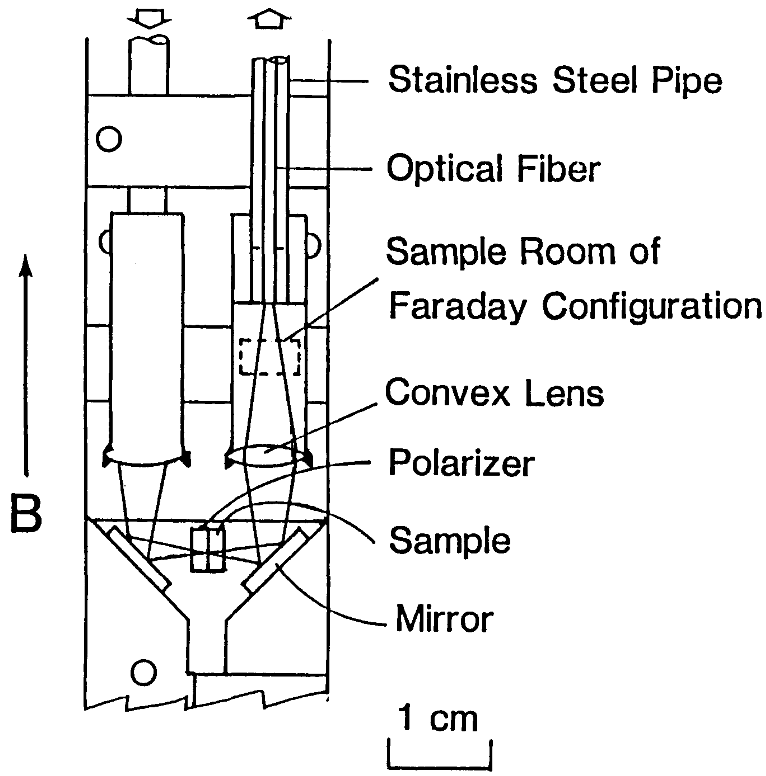

Fig. 2. Schematic view in the vicinity of sample. Sample is placed in Voigt configuration.

Detector. A photomultiplier of GaAs cathode (R758, Hamamatsu Photonics Co. Ltd.) is employed for the detection of visible light. This tube is almost equally sensitive from near violet to near infrared region, but the thermal noise level is 10 times higher than the usual photomultiplier at room temperature. The noise can be much reduced by cooling down the tube. A soild state refrigerator was used for cooling the tube down to -15 °C. The photomultiplier house with the refrigerator was also designed to shield the magnetic field up to 2 mT. Since the photomultiplier is very sensitive to the magnetic field, the detector was laid 10 m far from the hybrid magnet for avoiding the leakage flux. The flux density at that place was 0.5 mT, so that the effect of the stray fields was found to be negligible.

Arrangement. The arrangement of the magneto-absorption spectrometer is exhibited in Fig. 3. The hybrid magnet is placed at the first floor. We set up the monochromator at the mezzanine. During the magnet excitation, the magnet room is closed for the safety. Scanning of the wavelength and selection of the filters are remotely controlled as mentioned above. The experimentalists are in the room next to the resistive magnet room. The scale of the wavelength at the monochromator was monitored by an ITV camera. The measurements up to 14 T are carried out using the resistive magnet which is placed at the second floor.

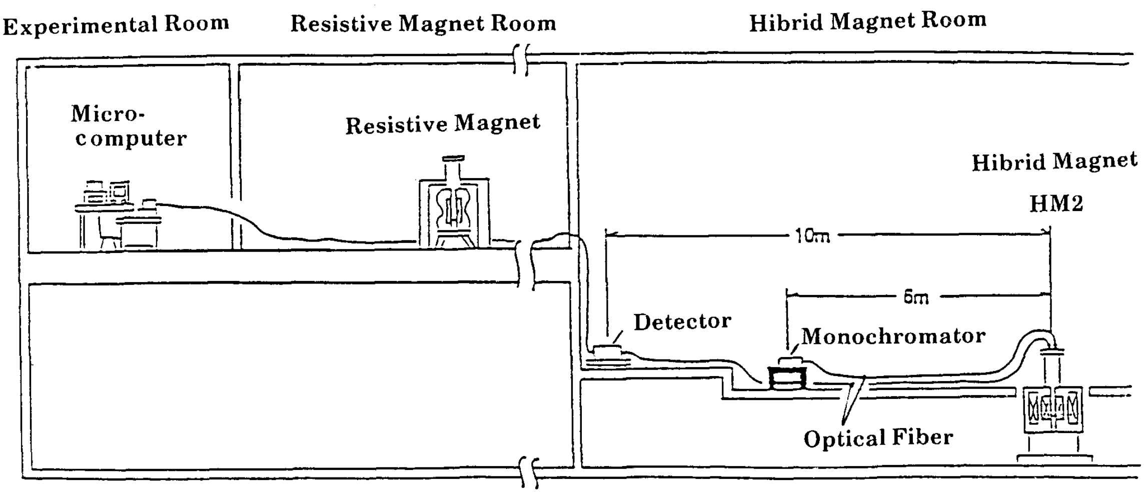

Fig. 3. Arrangement of the spectrometer.

Treatment of data. The light intensity is detected by a lock-in amplifier and converted to the digital signal by a digital multimeter. The digital signal is taken by the micro-computer in every 0.3 seconds. The transmission was measured step by step of wavelength. At each step the signals are taken several times. The average of signals was recorded in discs by the computer together with the wavelength. The number of sampling was adjusted 5 to 10 usually. The absorption coefficient was obtained numerically from the transmission data.

III. Examples of Magnetoabsorption Spectra

An example of magneto-absorption spectra taken by our apparatus is exhibited in Fig. 4. Manganese di-fluoride of the sample is an antiferromagnet (T_N = 67 K) having the rutile structure. The absorption peaks σ_1 and σ_2 are the magnon side band which has been

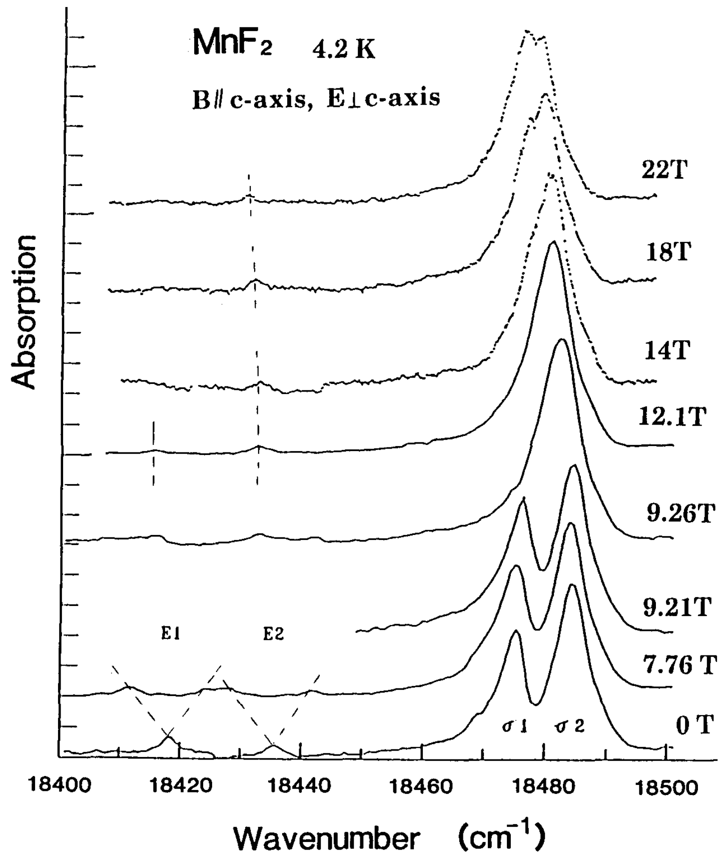

Fig. 4. Example of the magneto-absorption spectra in MnF_2. The absorption peaks denoted as σ_1 and σ_2 are the magnon side band.

identified in this substance for the first time[6]. By the way, the spectra of Fig. 4 are measured in the σ configuration: the propagation direction of the light (k) is perpendicular to the c-axis of the sample and the electric vector of the light (E) is parallel to the c-axis. The Voigt configuration is essential, when the magnetic field is applied parallel to the c-axis. The peaks σ_1 and σ_2 remain at the same energy up to the spin flop field of 9.24 T. Their positions change discontinuosly at the transition and exhibit lower energy shift with increasing the magnetic field above 10 T. Weak lines denoted as E_1 and E_2 are due to the exciton absorption which is the magnetic dipole transition. On the contrary, σ_1 and σ_2 are the electric dipole transition, in which the exciton absorption and the

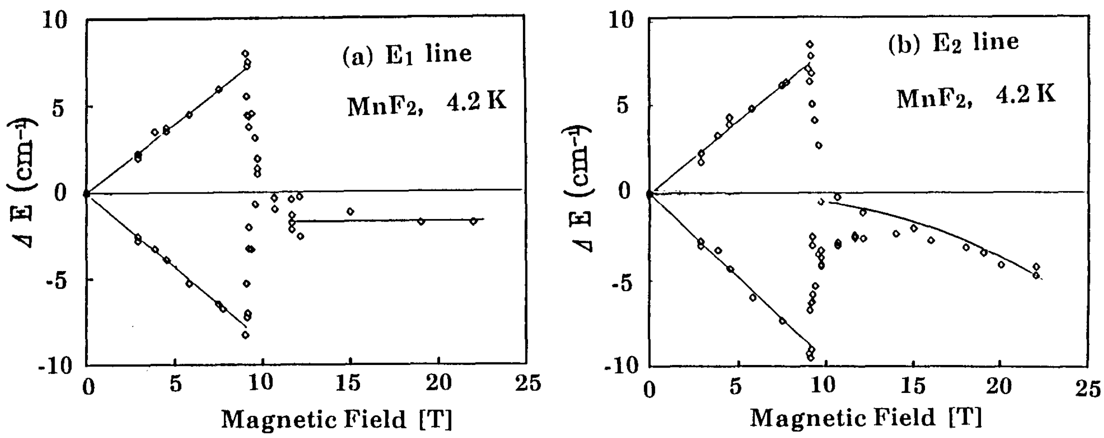

Fig. 5. Zeeman splitting of exciton absorption lines of (a) E_1 and (b) E_2. Above the transition field, E_2 line shows a large lower energy shift.

magnon excitation take place simultaneously[7]. Both E_1 and E_2 split into two lines, because the effect of the magnetic field differs between the antiferromagnetically ordered Mn spin at the body center and that at the corner in a unit cell. Above the spin flop transition, these lines exhibit no splitting, since the magnetic field energy is identical for the Mn spins. The E_1 line disappears in the field higher than 14 T, but it comes out clearly together with E_2 above 10 T in the π configuration ($k \perp c$, $E \parallel c$). The shift of the excition lines due to the magnetic field is plotted as a function of magnetic field in Fig. 5. It was found for the first time that the E_2 line considerably shifts in proportional to the square of the field, while E_1 remains at the same poisition. The strong field can clearly show the field dependence of the absorption spectra.

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